# Earth Science Mission Operations Project

## 428-10-09 Revision 1

# Afternoon Constellation Contingency Procedures

Revision 1

February 2011
Expires: February 2016

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National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

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# Afternoon Constellation Contingency Procedures
# Revision 1

## February 2011

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# Preface

This document is under the configuration control of the Earth Science Mission Operations (ESMO). The ESMO Project is responsible for processing changes to it. Proposed changes to this document will be submitted to the ESMO Configuration Control Board (CCB) along with supportive material justifying the changes. Changes to this document shall be made by Document Change Notice (DCN) or by complete revision following the Afternoon Constellation change approval process.

Questions concerning this document and proposed changes shall be addressed to:

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# Abstract

The purpose of this document is three-fold:

- Define what constitutes a contingency situation in the Afternoon Constellation
- Define the pertinent parameters involved in the contingency analysis
- Define the actions required, based on the results of the contingency analyses

As contingencies discussed here are primarily concerned with avoiding collisions, the key parameters for any action plan are the probability of collision, closest approach/miss distances, and the time remaining before closest approach occurs. Each contingency situation requires detailed analyses before any decisions are made.

**Keywords:** *NASA, ESMO, NPR, CNES, JAXA*

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# Section 1. Introduction

In accordance with National Aeronautics and Space Administration (NASA) Procedural Requirement (NPR) 8621.1b, NASA Procedural Requirements for Mishap Reporting, Investigating, and Recordkeeping, the Associate Administrator for Space Operations is responsible for ensuring that plans exist to manage contingencies affecting Earth Science programs, to carry out necessary investigations, and to report the results. Such plans and arrangements shall be consistent with NPR 8621.1B requirements.

## 1.1. Scope

These procedures designate key officials; establish responsibilities for managing and reporting contingencies affecting the Afternoon Constellation; and establish responsibilities for appointing contingency review boards and for conducting contingency investigations

This plan will be in effect until the conclusion of Afternoon Constellation operations. Other NASA, Centre National D'Etudes Spatiales (CNES) and Japan Aerospace Exploration Agency (JAXA) Offices are responsible for ensuring that contingency plans or equivalent exist to cope with Afternoon Constellation contingencies within their respective jurisdictions.

## 1.2. Applicability

This plan applies to NASA, CNES and JAXA offices with Afternoon Constellation mission responsibilities. Coordination with CNES missions will be as defined in the *Operational Interface Agreement (OIA) between CNES and CALIPSO for the Aqua Constellation* and in the *CALIPSO/PARASOL/ESMO Interface Control Document (ICD)*.

## 1.3. Referenced Documents

The most current version for each document below applies. The publications dates and version numbers listed are for reference only.

RD1. 428-10-08, Afternoon Constellation Operations Coordination Plan, February 2011.

RD2. NPR 8715.6A, NASA Procedural Requirements for Limiting Orbital Debris, May 14, 2009.

RD3. NPR 8621.1B, NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping, Expiration Date: May 23, 2011.

RD4. Afternoon Constellation / Landsat 5 Orbit Crossing Coordination Plan, October 2010.

RD5. "United States Strategic Command Joint Functional Component Command For Space and National Aeronautics And Space Administration Goddard Space Flight Center Interagency Operating Instruction for Robotic Missions Support", 25 Sep 2009.

## 1.4. Definition

For the purposes of this document, a contingency is defined as any mission-related failure, mishap or incident (involving flight or test hardware, support equipment, or facilities) that significantly delays or jeopardizes any Afternoon Constellation mission, or prevents accomplishment of a major (Level 1) objective. Specific classifications and definitions of types of mishaps are provided in NPR 8621.1B. For reference, Appendix B contains definitions for NASA Type-A, Type-B, and Type-C mishaps.

## 1.5. Changes

The Constellation Team Manager is responsible for maintaining this document. Requests for changes must be submitted to the Constellation Team Manager at NASA Goddard Space Flight Center for review, coordination, and action following the Afternoon Constellation change approval procedure described in RD1.

# Section 2. Definitions

Consistent use of terms will facilitate the discussion of contingency procedures. Readers are directed to the Afternoon Constellation Operations Coordination Plan (ACOCP) for an explanation of the Mission Operations Working Group (MOWG) (in Section 3.3), the Afternoon Constellation configuration (in Section 6), and Constellation coordination concepts (in Section 7). In the context of this Contingency Procedures document, the Control Box and the zone of exclusion (ZOE) require further elaboration beyond that contained in the ACOCP.

## 2.1. Contingency

An *anomaly* is an unplanned deviation from normal spacecraft operations. The fault can be either on the spacecraft or with the ground system.

In the context of the Afternoon Constellation, *safe-hold* is a spacecraft anomaly where the spacecraft has lost its ability to control its orbit. This is a serious anomaly since the spacecraft is unable to perform propulsive maneuvers. This results in pressure on the Flight Operations Team (FOT) to restore the spacecraft as quickly as possible back to its normal operating state. These are infrequent, unpredictable events. The recovery time from a safe-hold varies depending on the severity of the anomaly. Based on the Afternoon Constellation MOWG agreements, the satellite team's Constellation Coordination System (CCS) Mission Operator (CMO) is to set a "red" Satellite Status Flag on the CCS whenever their satellite has lost its ability to perform a propulsive maneuver.

A *Contingency* situation is a circumstance or condition within the constellation whereby a spacecraft is in a safe-hold condition and has drifted outside of its Control Box. A contingency situation is "contingent" on a prolonged safe-hold having occurred and can escalate in severity if the drifting satellite threatens to enter another satellite's Alert ZOE. If the drifting satellite violates its Control Box or within 5 days threatens to enter another satellite's Alert ZOE, the CMOs for the affected satellites are to set their Constellation status flag on the CCS to "yellow". With uncorrected drifting, eventually one satellite can make an unplanned close approach to another unless an evasive maneuver is performed. A contingency requires a coordinated action plan be established before the event. Specific actions must be defined and agreed to beforehand for both affected satellites.

## 2.2. Control Box

The ACOCP defines the Control Box as:

> *A theoretical construct centered at some reference position on a satellite's drag-free orbit with dimensions defined by an allowable along-track movement relative to the box's center (the reference position). In practice, this along-track movement is coupled with an*

> *East-West movement of the satellite's ground-track relative to the idealized ground-track of the drag-free orbit. It is this limitation in both the along-track and cross-track movements that creates the notion of a "box".*

Underlying the east-west movement of the satellite's ground track is the Worldwide Reference System –2 (WRS-2); please refer to the ACOCP Appendix C for more information on the WRS-2.

The *Control Box* construct was established originally to address science requirements, that is, to maintain optimal spacing of satellites to maximize science returns without requiring a great deal of active coordination between Control Centers. If a satellite stays within its own Control Box, it should never create a collision risk to any other constellation satellite. The Control Box provides an "early warning" if a satellite leaves its designated area and *potentially* threatens another constellation satellite.

The Afternoon Constellation Control Box configuration is defined in the ACOCP (Figure 2-1). Aqua, Aura, Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) all maintain Control Boxes that are ± 10 kilometers measured along the equator (corresponding to ± 21.5 seconds in equator crossing time). The CloudSat mission is slaved to CALIPSO. Its control box is ± 2.5 km as measured along the equator around a point that is 17.5 seconds in front of CALIPSO.

PARASOL stopped maintaining the sun synchronous inclination after the planned Spring 2007 inclination maneuver series. On December 2, 2009, PARASOL lowered its orbit by 4 km and broke with the standard Afternoon Constellation orbital configuration.

The Glory, Global Change Observation Mission 1st-Water (GCOM-W1), and Orbiting Carbon Observatory-2 (OCO-2) Control Boxes are ± 20 kilometers measured along the equator (corresponding to ± 43 seconds in equator crossing time).

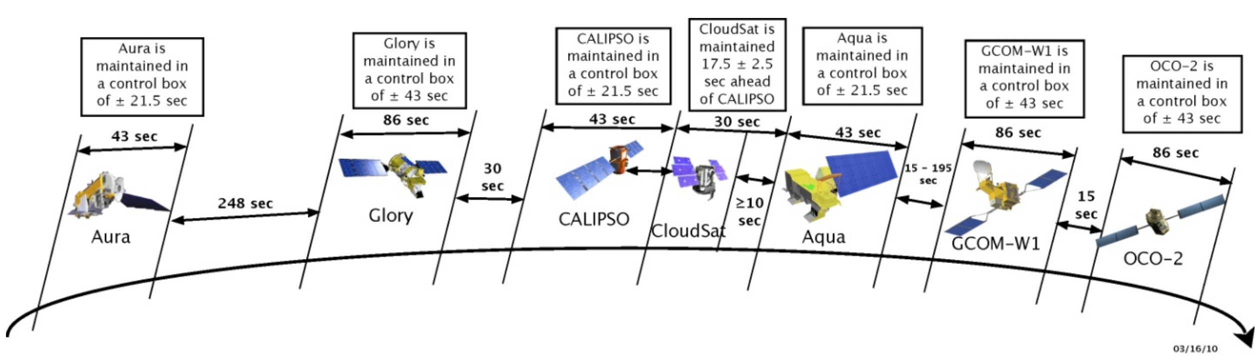


***Figure 2-1. Afternoon Constellation Orbit/Formation Maintenance Plan***

Satellites move in a predictable fashion within their Control Box (Figure 2-2). This motion is a called a *circulation orbit* and represents the relative motion of each satellite in its Control Box. Atmospheric drag slows the satellite, dropping its altitude, thereby making the satellite speed up relative to its "fixed" control box. Eventually, the satellite needs to perform an orbit-raising maneuver in order to stay within its box. This moves the satellite above its mean semi-major axis (SMA) altitude, so that it is slower relative to the center of its control box. Drag takes over, forcing the satellite to a lower orbit, then the cycle repeats.

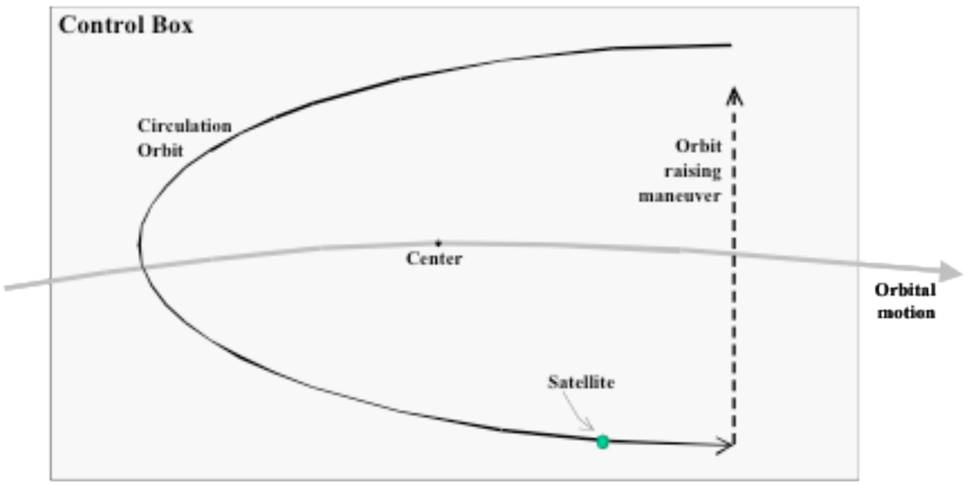


*Figure 2-2. Control Box/Circulation Orbit Relationship*

CloudSat represents a special case in that it will fly in formation with CALIPSO at a spacing of 17.5 ± 2.5 seconds (in equator crossing time) in the direction of Aqua (Figure 2-3). Though there is a 30-second buffer between the CALIPSO and Aqua Control Boxes, the CloudSat satellite can be as close as 10 seconds to the trailing edge of Aqua's Control Box.

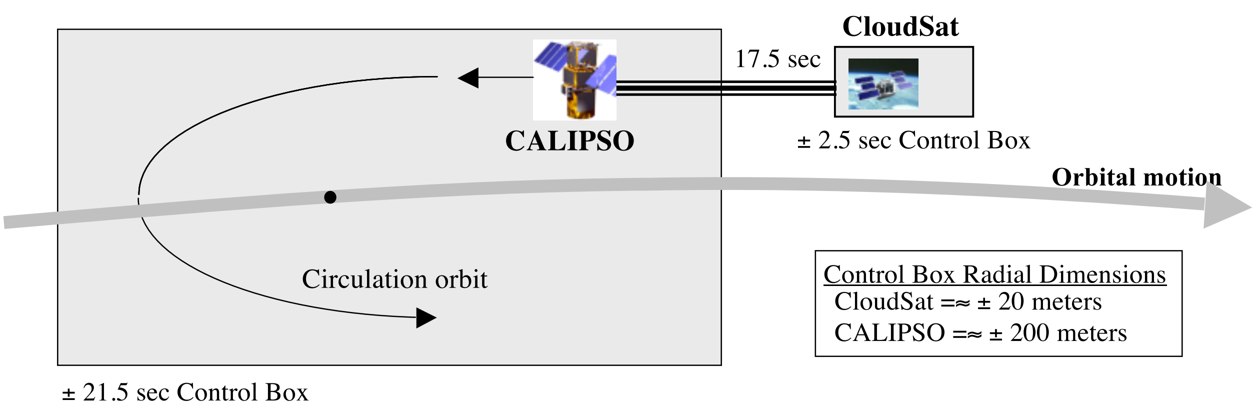


*Figure 2-3. CloudSat/CALIPSO Formation Flying*

## 2.3. Zone of Exclusion

The ACOCP defines a ZOE (Figure 2-4) as "***A rectangular region in a satellite radial, in-track, cross-track (RIC) coordinate system***" centered on each of the Constellation's satellites (note that some organizations use the equivalent coordinates of "UVW" in place of "RIC").

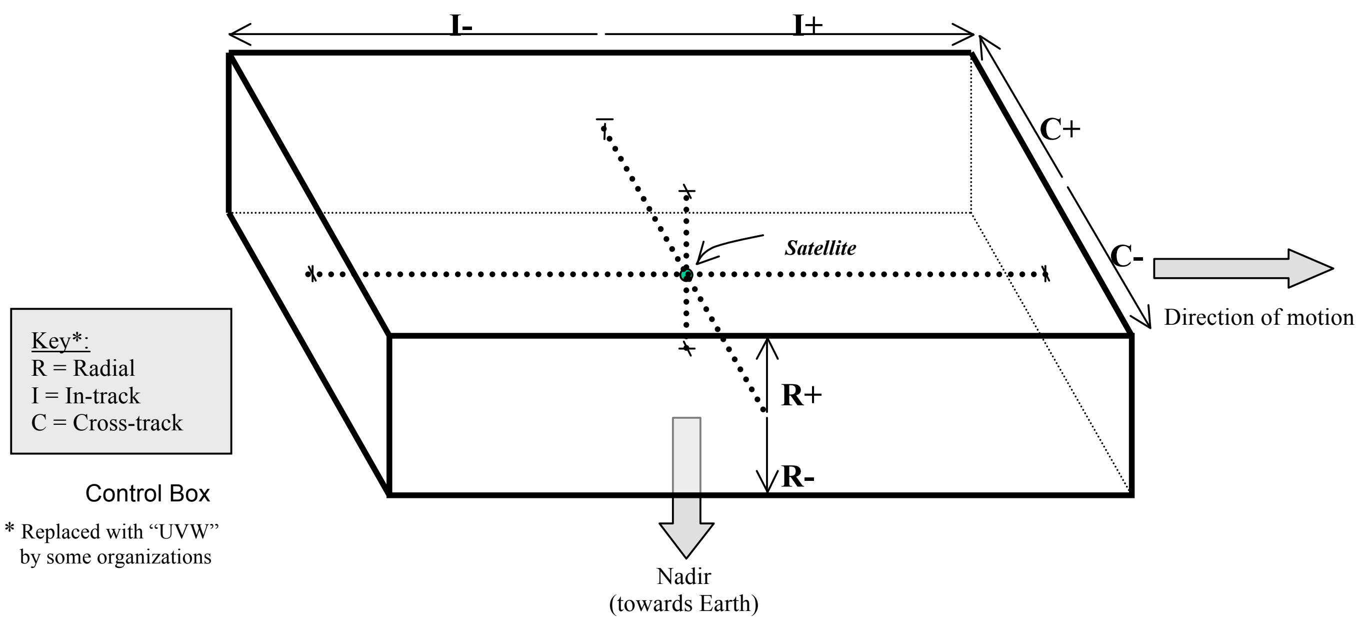


***Figure 2-4. Zone of Exclusion***

There are two ZOEs (Figure 2-5) with the dimensions defined in Table 2-1:

- *Alert ZOE*
- *Action ZOE*

Note that these dimensions have been set empirically, not through any study of possible values. For comparison, note also that a mission's ZOE is much smaller than its Control Box in the in-track direction, but larger in the radial and cross-track directions.

***Table 2-1 Zone of Exclusion (ZOE) Dimensions***

| ZOE | Radial (km) | In-Track (km) | Cross-track (km) |
|---|---|---|---|
| Alert ZOE | ± 2 | ± 25 | ± 25 |
| Action ZOE | ± 0.5 | ± 5 | ± 5 |

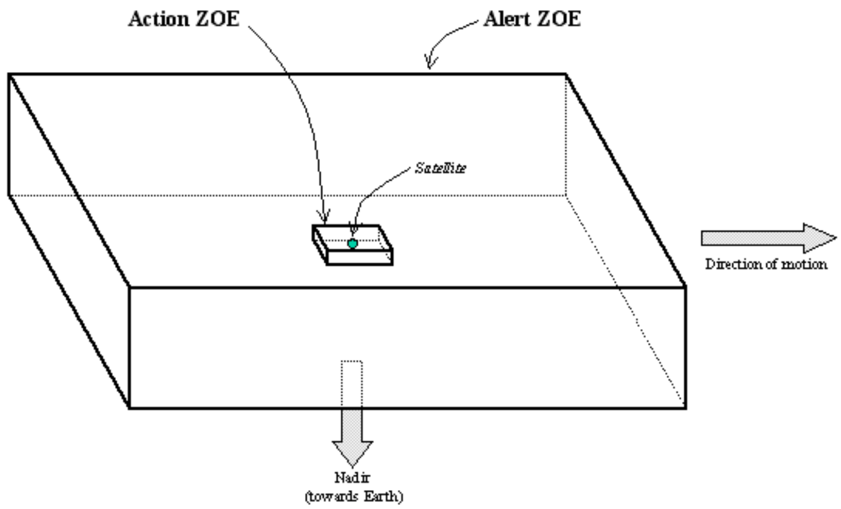


*Figure 2-5. ZOE Relationships*

This 2-tier structure reflects the difference in concern in the two volumes. For example, a satellite that is just inside the Alert ZOE does not present an immediate danger, whereas a satellite that enters an Action ZOE may be a cause for action.

- The Alert ZOE is used to provide notifications to affected missions of a potential close approach. Predicted entry into this region is cause for concern, but not necessarily immediate reaction. The Alert ZOE defines a "keep-out" or "no-go" zone for other satellites. A close approach between two Constellation satellites that is inside of the ZOE may be considered unsafe by representing an unacceptable level of risk of collision. Orbit prediction tools are accurate enough, even including uncertainties, that if the Alert ZOEs are honored during maneuver design there is no chance of collision with another satellite.

  An Alert ZOE violation by any satellite is the basis for setting the Red Constellation Status flag in the CCS, as the violation creates an elevated risk to the satellites.

- An Action ZOE violation signifies a higher risk of a collision than an Alert ZOE violation and is to be avoided, if possible, by use of an evasive maneuver. If an Action ZOE violation is predicted to occur, the functioning satellite team may decide to maneuver its satellite out of the way of the approaching object. The decision will be based on a number of factors, including probably of collision (Pc) and orbit geometry – please refer to RD5 for more specific discussion of close approach handling procedures. Note that when a functioning satellite maneuvers in order to pass above (or below) another satellite in the Constellation it shall do so in a manner such that neither satellite's Action ZOE is violated (taking into account 3 sigma errors in orbit determination and maneuver execution).

## 2.4. Constellation Flags

Mission teams have agreed to set three status flags for their mission based on the following definitions. The **Constellation Status** flag represents the status of the satellite relative to its configuration within the Constellation (Table 2-2). The **Satellite Status** flag represents the status of the individual satellite (see Table 2-3). The **Instrument Status** flag represents the status of the instrument(s) on an individual satellite (see Table 2-4). These flags are defined in the ACOCP, but are repeated here for convenience.

The CCS does not autonomously set these flags. This responsibility rests with the authorized CMO designated for each mission. The CMO goal is to set a flag within 8 hours of determining that a qualifying event has occurred.

***Table 2-2 Constellation Status Flag Definitions***

| FLAG | TYPE | ACTION | DEFINITION |
|---|---|---|---|
| **RED** | ZOE violations | Action is required immediately | An Alert ZOE violation has occurred. |
| **YELLOW** | Control Box violations | Action may be required, but not immediately | Does not qualify as RED, but a Control Box violation has occurred *OR* an Alert ZOE violation is predicted to occur during the next 5 days. |
| **GREEN** | Nominal operations | No action is required | Does not qualify as RED or YELLOW. That is, the satellite is in its control box and no Alert ZOE violations have occurred or are predicted to occur during the next 5 days. |
| | | | |

***Table 2-3 Satellite Status Flag Definitions***

| FLAG | TYPE | DEFINITION |
|---|---|---|
| **RED** | Safe Hold | The satellite has entered a state or a mode whereby it has lost its ability to perform a propulsive maneuver. |
| **YELLOW** | Subsystem Interruption | One or more of the instruments is in non-nominal state and therefore not generating science data, or a satellite bus subsystem, such as the command and data handling system, is not operational, thus science data are not being downlinked. |
| **GREEN** | Nominal operations | The satellite is able to maneuver as required and is collecting and returning science data. |
| | | |

*Table 2-4 Instrument Status Flag Definitions*

| FLAG | TYPE | DEFINITION |
|---|---|---|
| RED | Inoperative | An instrument is not capable of collecting science data. |
| YELLOW | Degraded operations | An instrument's performance is degraded. |
| GREEN | Nominal operations | All instrument performance is nominal. |
| | | |

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# Section 3. Contingency Procedure Overview

Most, but not all of the identified contingency situations involve one functioning satellite being threatened by a non-functioning satellite, so it is useful to provide an overview of this generic situation before getting into more specific scenarios. In this context, a *functioning* satellite has the propulsive capability to change its orbit, while a *non-functioning* satellite (e.g., in safe-hold) does not. Note that this scenario is predicated on the satellites having achieved their operational orbits. This section does not address launch and early orbit (L&EO) operations prior to reaching an operational orbit.

This generic approach can be extended to scenarios other than potential collisions. Execution of a contingency procedure will go through several stages. Each successive stage represents an escalation in the contingency:

- Monitoring and Detection
- Analysis
- Notification and Coordination
- Maneuvers

## 3.1. Monitoring and Detection

Monitoring is performed in two primary methods:

- Each Control Center monitors the position of its satellite.
- Each Control Center provides ephemerides on a daily/weekly basis to the CCS tool. At the receipt of the ephemeris files, CCS automatically performs its analyses of orbital positions of all satellites.

Using the data, both the Control Center and the CCS can determine:

- Is the satellite still in its Control Box?
- Will it remain in its Control Box for the span of the predictive ephemeris?

## 3.2. Analysis

If any satellite has left (or will leave) its Control Box, the CCS will automatically perform additional analyses to determine the likelihood that the satellite will endanger any other.

The results of these analyses will include the following:

- When will the satellite leave its Control Box?

- Will the satellite enter the ZOE of another satellite? If so, when?
- What will be the separation at closest approach?

## 3.3. Notification and Coordination

Coordination starts with the satellite operations teams in each Control Center. Note that in the context of this document, the CALIPSO MOCC and SOCC are considered a single Control Center.

Clearly, each Control Center will be fully aware of an impending contingency situation caused by its own satellite. One of the main purposes of the CCS is to supplement this by alerting a team via an e-mail to its CMO that its satellite may be threatened by the approach of another satellite.

Regardless of how a potential contingency is detected, the notification to the affected Control Centers shall be handled in the following manner. If a Control Center becomes aware of a potential contingency situation, whether through its own analysis or through the analysis of the CCS, it shall notify the affected Control Center(s) directly through e-mail and, if time is short, by telephone. The Control Center shall use the list of contacts in Appendix A (or as updated in the future). This notification begins the coordination phase.

The affected teams will coordinate their actions in accordance with the ACOCP and the procedures contained herein. The Control Centers shall maintain communication throughout the period of contingency and corrective measures.

## 3.4. Maneuvers

First and foremost, the goal of this coordination shall be to return each satellite to its Control Box. The satellite that left (or will leave) its Control Box has the prime responsibility to make correctional maneuvers and return to its Control Box.

If this is not possible, steps shall be taken by the other satellites to ensure that potential close approaches and/or collisions are avoided at all costs. If the drifting satellite has no orbital control, the responsibility for self-preservation falls upon the threatened satellite(s). The threatened satellite(s) shall execute evasive maneuvers to prevent unacceptably close approaches with any other satellite.

If any of these maneuvers cause additional satellites to leave their Control Boxes, an action plan shall be identified to either return all functioning satellites to their Control Boxes once the danger has passed, or if necessary, seek approval to change the Afternoon Constellation configuration. A configuration change is not to be approached lightly since this may cause additional science and operational concerns.

# Section 4. Contingency Procedures

Several specific contingencies have been identified. Analysis of each specific contingency situation is critical to establish a timeline when actions (e.g., evasive maneuvers) must be performed. Each of the identified scenarios is examined in turn in the following sections.

## 4.1. Aqua, CloudSat, Aura, Glory, GCOM-W1, or OCO-2 In A Prolonged Safehold

**OVERVIEW**

Most potential contingency situations involve one satellite lacking orbital control, call it Satellite B (think "*Broken*") that is approaching a functioning satellite, call this one Satellite A (think "*A-OK*") (see Figure 4-1). If Satellite B remains without orbital control, it will drift and may eventually threaten Satellite A. Satellite A may need to execute maneuvers to avoid Satellite B. Debris from a collision could pose a risk for the entire Constellation.

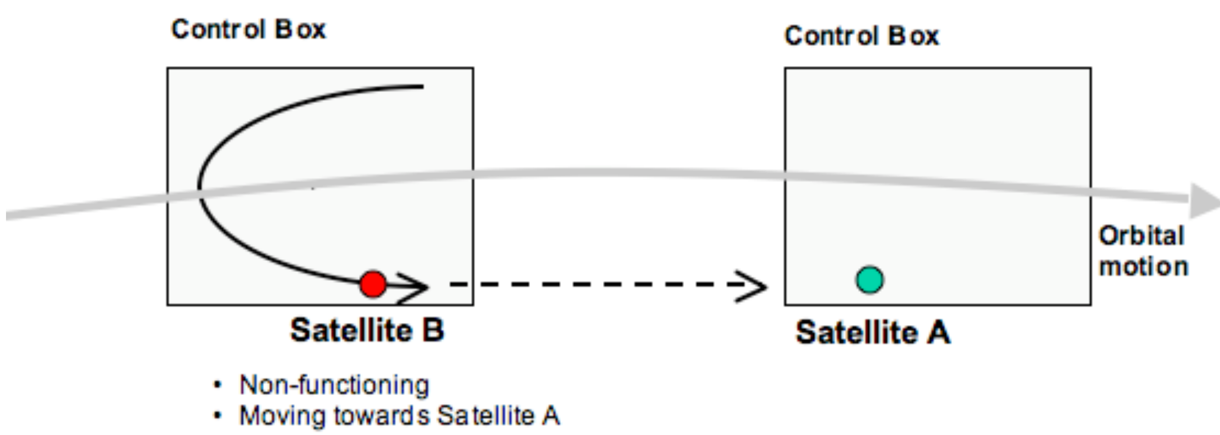


*Figure 4-1. Collision Avoidance Scenario With Satellite A and Satellite B*

## PROCEDURE

| | |
|---|---|
| **Step 1** | Once the Control Center has determined that Satellite B has lost orbital control, the CMO of the Satellite B team shall set its Satellite Status flag to “Red” and enter explanatory text into CCS (see Figure 4-2).<br>The CMO shall select the e-mail options to contact all mission CMOs.<br>CCS shall send an e-mail notifications to all CMOs and the ESMO Constellation management group and any additional recipients designated by the mission CMO announcing this Satellite status flag change. |

### Set Satellite Status View

| | Mission | Status | Description | Email Text | Email Groups |
|---|---|---|---|---|---|
| Edit | OCO-2 | gray | Not launched | Enter Text | Enter Recipients |
| Edit | GCOM-W1 | gray | Not launched | Enter Text | Enter Recipients |
| Edit | Aqua | green | Normal Operation | Enter Text | Enter Recipients |
| Edit | CloudSat | green | | Enter Text | Enter Recipients |
| Update Cancel | CALIPSO | green<br>green<br>yellow<br>red<br>gray | CALIPSO was launched on April 28, 2006 | | **ESMO Mgmt Group**<br>Mission Administrators<br>Mission Operators<br>Authorized Users |
| Edit | Parasol | green | Normal Operation | Enter Text | Enter Recipients |
| Edit | Glory | gray | Not Launched | Enter Text | Enter Recipients |
| Edit | Aura | green | Normal Operation | Enter Text | Enter Recipients |

***Figure 4-2. Setting the Constellation Status Flag in CCS***

| | |
|---|---|
| **Step 2.** | The Satellite B team shall generate a new, predictive ephemeris based on no maneuvers and current atmospheric drag conditions and then upload this ephemeris to the CCS, if required.<br>CCS shall perform its standard processing for the duration of this new ephemeris to identify any Control Box violations and, if indicated, any Close Approach violations. CCS will display the relative position of the satellite on its web site. |
| **Step 3.** | If/when Satellite B is predicted to leave its Control Box, CCS shall:<br>a. Send an e-mail notification to the Satellite B CMO and the ESMO Constellation management group indicating the date/time of the Control Box violation, and<br>b. Initiate a Close Approach analysis in order to compare Satellite B’s ephemeris with that from the other Afternoon Constellation satellites.<br>Note that,<br>• The e-mail notifications and analysis will be performed every time that CCS receives a new ephemeris from Satellite B that predicts a control box excursion, and<br>• The other satellite CMOs will *not* automatically be notified of the Control Box violation at this time (i.e., Satellite B team is not *required* to contact any other team yet) |

**Step 4.**

If/when Satellite B leaves its Control Box, the Satellite B CMO shall set its Constellation Status flag in CCS to “Yellow” (see Figure 4-3).

CCS shall then send e-mail notifications to all CMOs and the ESMO Constellation management group.

**Set Constellation Status View**

| | Mission | Status | Description | Email Text | Email Groups |
|---|---|---|---|---|---|
| Edit | OCO-2 | gray | Not launched | Enter Text | Enter Recipients |
| Edit | GCOM-W1 | gray | Not launched | Enter Text | Enter Recipients |
| Edit | Aqua | green | Normal Operation | Enter Text | Enter Recipients |
| Edit | CloudSat | green | In Formation | Enter Text | Enter Recipients |
| Update Cancel | CALIPSO | green<br>green<br>yellow<br>red<br>gray | CALIPSO was launched on April 28, 2006 | | **Mission Operators**<br>**ESMO Mgmt Group**<br>Mission Administrators<br>Authorized Users |
| Edit | Parasol | green | Normal Operation | Enter Text | Enter Recipients |
| Edit | Glory | gray | Not Launched | Enter Text | Enter Recipients |
| Edit | Aura | green | Normal Operation | Enter Text | Enter Recipients |

***Figure 4-3. Setting the Satellite Status Flag in CCS***

| | |
|---|---|
| **Step 5.** | If the Close Approach analysis (through the duration of both ephemerides) predicts that Satellite B will enter the Alert ZOE of any other Constellation satellite (specifically Satellite A in this example),<br>a. CCS shall send an e-mail notification to the CMOs of both Satellite A and Satellite B and to the ESMO Constellation management group. This e-mail notification will include the date/time of closest approach and the predicted range. These e-mail notifications and analyses will be performed every time that CCS receives a new ephemeris from either Satellite A or from Satellite B.<br>b. If the Alert ZOE violation is predicted to occur within the next 5 days, both the Satellite A and Satellite B CMOs shall set their Constellation Status flags in CCS to “Yellow” (see Figure 4.3 above). CCS will then send e-mail notifications to all CMOs and the ESMO Constellation management group.<br>c. The Satellite A and Satellite B teams shall discuss via e-mail (and if appropriate, via telephone) the situation and their respective plans for resolution. The ESMO Constellation management group may participate if desired.<br>d. The Joint Space Operations Command (JsPOC) routinely screens all Afternoon Constellation satellites against the catalogue of resident space objects, including Satellites A and B. With this information, it will provide to the ESMO Project a predicted miss distance between Satellite A and Satellite B.<br>e. The Satellite A and Satellite B teams shall determine whether the predicted close approach occurs inside their respective Action ZOEs and whether it requires an evasive maneuver by Satellite A. This decision will take into account numerous factors, including but not limited to:<br>• The $P_c$<br>• The predicted miss distance or range<br>• The uncertainties in the ephemeris data at the time of closest approach<br>• The time remaining before closest approach<br>When a functioning satellite maneuvers in order to pass above (or below) another satellite in the Constellation it shall do so in a manner such that neither satellite’s Action ZOE is violated (taking into account 3 sigma errors in orbit determination and maneuver execution).<br>The Satellite A and B teams shall notify all Constellation teams and the ESMO Constellation management group within 24 hours of the decision to conduct (or not conduct) an evasive maneuver.<br>If the Satellite A team feels that an evasive maneuver is required, their team will proceed with maneuver planning (see Step 6).<br>If both teams agree that no evasive maneuver is required by Satellite A, no additional action is required until Satellite B has left the Alert ZOE of Satellite A (see Step 7).<br>If there is a disagreement as to any proposed course of action that cannot be resolved through discussion and negotiation, then the conflict resolution procedure outlined in the ACOCP Section 6, shall be invoked. Due to the nature of the problem, there must be sufficient time allotted for the conflict resolution process to run its course. |

| | |
|---|---|
| **Step 6.** | If an evasive maneuver *is* planned,<br>a. The Satellite A and Satellite B teams shall conduct a teleconference with the ESMO Constellation management group no later than 48 hours (if possible) before any expected close approach. The teams shall describe the type of maneuver being planned (e.g., orbit-raising, orbit lowering, inclination change, etc.) and provide assurances that it will not endanger any other Constellation missions.<br>b. The Satellite A team shall provide an updated ephemeris (including the planned maneuver) to CCS.<br>c. CCS shall perform its standard processing on the burn ephemeris (including its close approach analysis) to independently confirm the expected results.<br>d. Not later than 24 hours before any expected close approach with Satellite B, the Satellite A team shall:<br>• Execute its evasive maneuver plan<br>• Notify the other Constellation teams of the maneuver's success/failure<br>• Supply an updated post-burn predictive ephemeris to CCS.<br>e. Using the latest ephemeris, CCS shall perform its close approach analysis, which can then be used to verify that the close approach has been avoided. Note that e-mail messages will continue to be sent until the satellite has left the Alert ZOE. |
| **Step 7.** | Once Satellite B has left the Alert ZOE of Satellite A,<br>a. The Satellite B CMO shall change its Constellation Status Flag from "Red" to "Yellow"<br>b. The Satellite A CMO shall change its Constellation Status Flag from "Red" to "Green" (if still inside its Control Box) or to "Yellow" (if the maneuver had forced it to move outside its Control Box) |

## ADDITIONAL CONSIDERATIONS

| | |
|---|---|
| **A.** | The mission science teams/Project Scientists shall be kept informed of any circumstance that interferes with science observations and data collection. In addition, all other Constellation teams shall monitor the situation and provide constructive feedback to both the Satellite A and Satellite B teams, as appropriate. |

| | |
|---|---|
| **B.** | During the entire period, the Satellite B team shall attempt to regain orbital control. If successful,<br>a. The Satellite B CMO shall set its Satellite Status Flag in CCS to "Green". The CMO shall select the e-mail options to contact all mission CMOs.<br>b. CCS will then send out e-mail notifications to all CMOs and the ESMO Constellation management group.<br>c. If appropriate, the Satellite B team shall immediately notify the Satellite A team (and any others) via telephone.<br>d. If Satellite B is outside its Control Box, the Satellite B team shall plan a safe return route. There are 2 general scenarios (see Figure 4-4).<br>• In a "Simple Return" (i.e., Satellite B had never passed any other satellite), the return to its Control Box can be executed with little discussion (although missions without retrograde maneuver capability may have additional complications).<br>• In a "Complex Return" (i.e., Satellite B had already passed at least one satellite), discussions with other Satellite teams will be required to ensure a safe, coordinated return to its Control Box. In no case shall a functioning Satellite B violate the Alert ZOE of any other satellite unless permission to do so has been provided by that satellite team.<br>e. In either scenario, the Satellite B teams shall follow the standard collision avoidance procedures in this section (e.g., announce its maneuver plans; provide predictive ephemeris to CCS; then execute the maneuvers). Once inside its Control Box, the Satellite B CMO shall set its Constellation Status Flag to "Green". CCS will then send an e-mail message to the Satellite B CMO confirming the status flag change. |
| **C.** | If the Satellite B team cannot regain orbital control, *or* it has regained orbital control but has decided not to return its satellite to the Afternoon Constellation (for any reason), it shall submit a report of its findings to the MOWG, providing the following information:<br>a. Reason for change<br>b. New orbital parameters<br>c. Impact on operations<br>d. Impact on coordinated science within the Constellation<br>e. Impact on documentation<br>The MOWG shall then officially acknowledge that Satellite B has left the Constellation. |
| **D.** | If any satellite team wishes to change its location within the Afternoon Constellation permanently due to these events (or for any reason), it must seek the approval of the MOWG. A Constellation configuration change is not to be approached lightly since this may cause additional science and operational concerns. The team shall submit its request to the MOWG, via an Afternoon Constellation Configuration Change Request (CCR), providing the following information:<br>a. Reason for change<br>b. New orbital parameters<br>c. Impact on operations<br>d. Impact on coordinated science within the Constellation<br>e. Impact on documentation<br>The MOWG shall conduct a meeting within 30 days of the request (sooner if this is an urgent request). Most likely this meeting shall be conducted via a teleconference. A recommendation shall be provided after no more than seven days. |

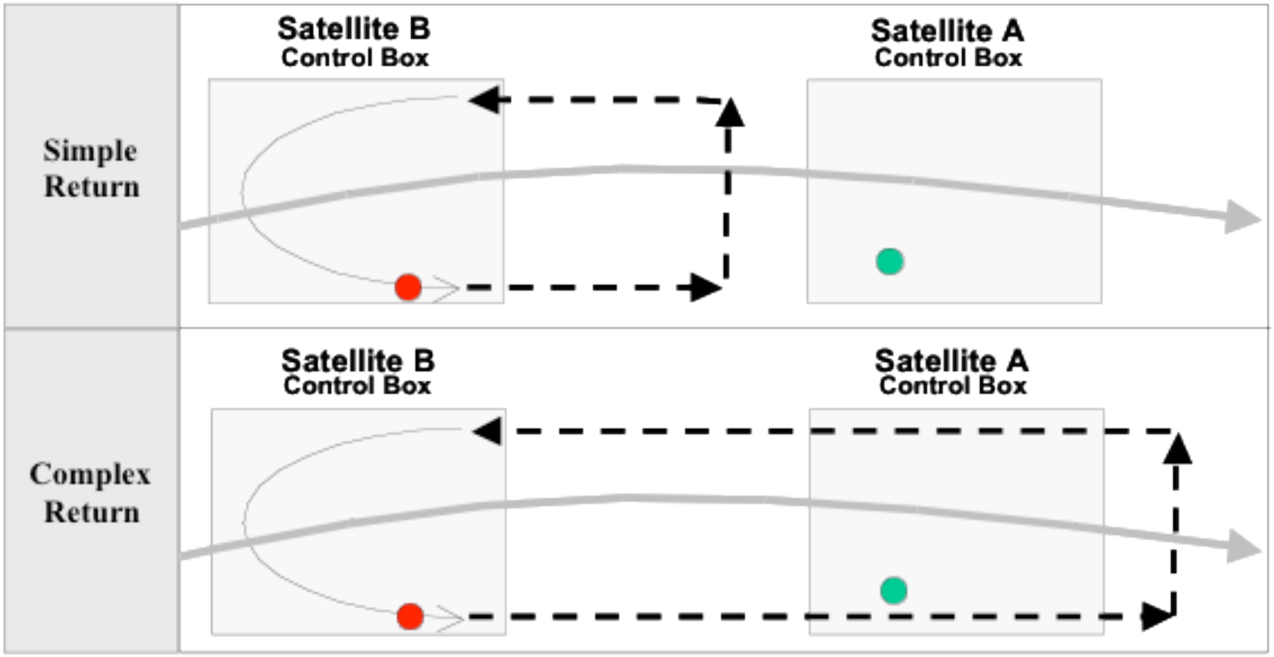


*Figure 4-4. Control Box Return Scenarios*

### 4.1.1. Aqua In A Prolonged Safe-hold

**DESCRIPTION**

If Aqua remains in a prolonged safe-hold, it will be unable to counteract the effects of atmospheric drag which lowers Aqua's altitude, causing it to speed up and drift forward. If this movement is unchecked, Aqua may eventually threaten GCOM-W1 and possibly OCO-2 (see Figure 4-5).

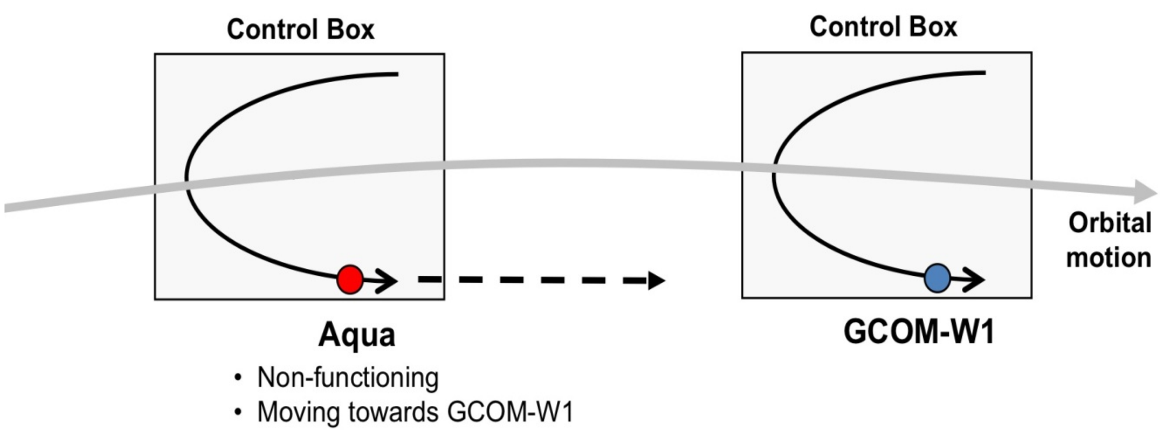


*Figure 4-5. Collision Avoidance Scenario Between Aqua and GCOM-W1*

**ANALYSIS**

Aqua is located at the "front" of the Afternoon Constellation (until the launches of GCOM-W1 and OCO-2). If it begins to drift, it will move away from the rest of the Constellation and will pose no current threat to any other satellite. Once GCOM-W1 and OCO-2 join the Afternoon Constellation, any drift by Aqua would pose a threat to these two missions.

A separate issue for the Constellation will be the loss of the Aqua satellite and instruments for science coordination. The role of Constellation "lead" will need to be reassigned.

**PROCEDURE**

| | |
|---|---|
| **Step 1** | The standard collision avoidance procedure in Section 4.1 shall be followed to ensure that there is no unacceptable close approach between Aqua (as Satellite B) and the GCOM-W1 or OCO-2 missions (as Satellite A). |

| | |
|---|---|
| **Step 2.** | Initially the Constellation teams shall continue to use the "Virtual" Aqua (VA) location on the WRS-2, the location that represents the motion of Aqua if drag were not present. (Note: At any given instant the Mean Local Time (MLT) of VA's ascending node is identical to the MLT of real Aqua, which is to say their orbit planes are identical. VA always has its sub-satellite point on the WRS II groundtrack. VA defines the Constellation configuration). |
| **Step 3.** | If it is determined that Aqua will not maintain its location in the Constellation, the MOWG and science teams shall convene to discuss alternative proposals, including replacing Aqua with another satellite to serve as the "leader". Collectively, the MOWG and science teams shall agree upon a new approach to be followed by all teams. |
| | |

### 4.1.2. CloudSat In A Prolonged Safe-hold

**DESCRIPTION**

If CloudSat remains in a prolonged safe-hold, it will drift and eventually may enter CALIPSO's Alert ZOE (see Figure 4-6).

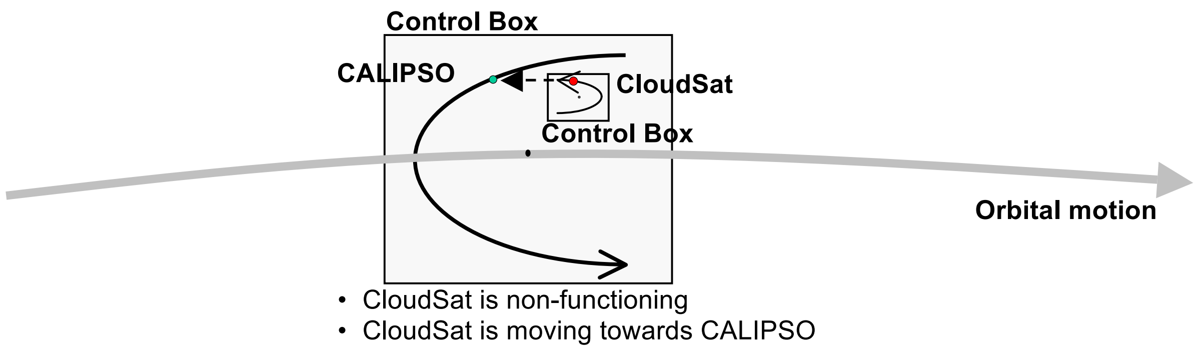


*Figure 4-6. Collision Avoidance Scenario Between CloudSat and CALIPSO*

**ANALYSIS**

CloudSat nominally moves along its circulation orbit in 13 to 50 days (depending on the level of atmospheric drag). As such, the "worst–case" scenarios addressed below may be favorably biased by up to 13-50 days, depending on *where* in the circulation orbit the safe-hold occurs.

Under the highest recorded atmospheric drag while at the worst location:

- CloudSat will enter CALIPSO's Alert ZOE in about 7 days
- A CloudSat close approach with CALIPSO will occur in about 10 days.

Under typical atmospheric drag while at the worst location:

- CloudSat will enter CALIPSO's Alert ZOE in about 15 days
- A CloudSat close approach with CALIPSO will occur in about 24 days.

**PROCEDURE**

| |
|---|
| The standard collision avoidance procedure in Section 4.1 shall be followed to ensure that there is no unacceptable close approach between CloudSat (as Satellite B) and CALIPSO (as Satellite A). |

### 4.1.3. Glory In A Prolonged Safe-hold

**DESCRIPTION**

If Glory remains in a prolonged safe-hold, it will drift and may eventually enter CALIPSO's Alert ZOE (see Figure 4-7).

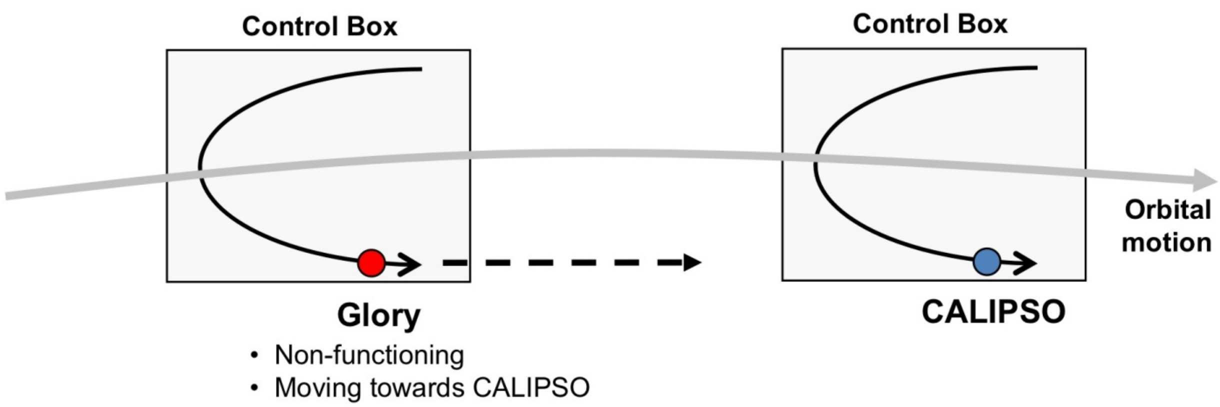


*Figure 4-7. Collision Avoidance Scenario Between Glory and CALIPSO*

**ANALYSIS**

Several days or weeks are expected to elapse before Glory drifts sufficiently to threaten CALIPSO.

**PROCEDURE**

| |
|---|
| The standard collision avoidance procedure in Section 4.1 shall be followed to ensure that there is no unacceptable close approach between Glory (as Satellite B) and CALIPSO (as Satellite A). |

### 4.1.4. Aura In A Prolonged Safe-hold

**DESCRIPTION**

If Aura remains in a prolonged safe-hold, it will drift and may eventually enter Glory's Alert ZOE (see Figure 4-8).

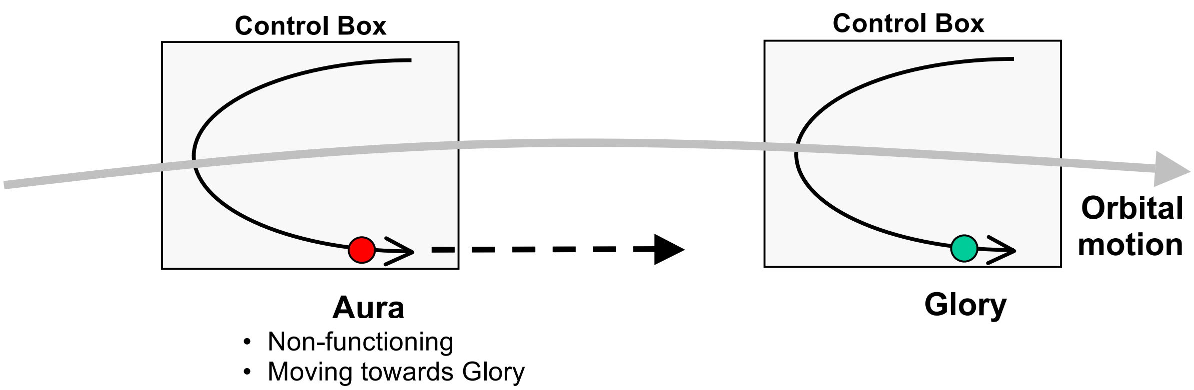


*Figure 4-8. Collision Avoidance Scenario Between Aura and Glory*

**ANALYSIS**

If Aura begins to drift, it will move closer to the Glory satellite. It will take several weeks for Aura to drift to the vicinity of Glory, allowing plenty of time to react using the standard collision avoidance procedure.

**PROCEDURE**

| |
|---|
| The standard collision avoidance procedure in Section 4.1 shall be followed to ensure that there is no unacceptable close approach between Aura (as Satellite B) and Glory (as Satellite A). |

### 4.1.5. GCOM-W1 In A Prolonged Safe-hold

**DESCRIPTION**

If GCOM-W1 remains in a prolonged safe-hold, it will drift and may eventually enter OCO-2's Alert ZOE (see Figure 4-9).

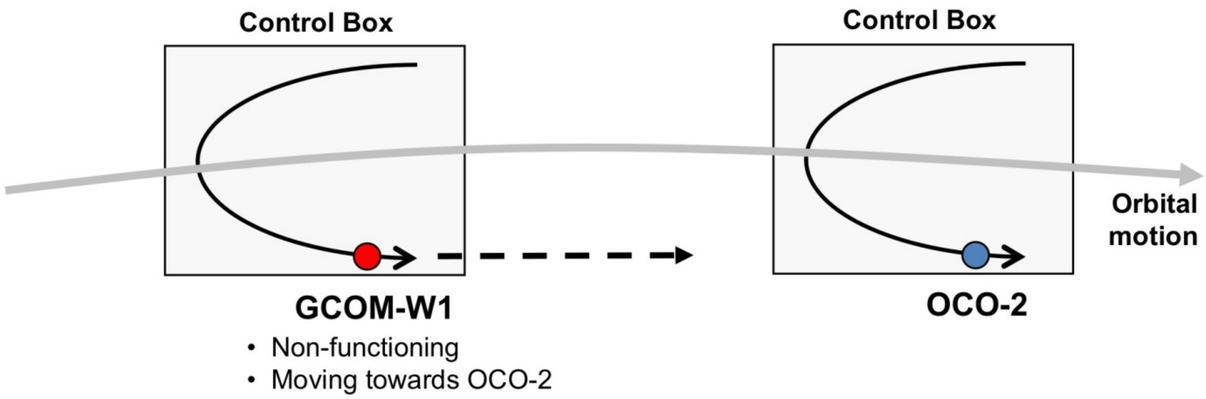


*Figure 4-9. Collision Avoidance Scenario Between GCOM-W1 and OCO-2*

**ANALYSIS**

If GCOM-W1 begins to drift, it will move closer to the OCO-2 satellite. It will take several days or weeks for GCOM-W1 to drift to the vicinity of OCO-2, allowing plenty of time to react using the standard collision avoidance procedure.

**PROCEDURE**

| |
|---|
| The standard collision avoidance procedure in Section 4.1 shall be followed to ensure that there is no unacceptable close approach between GCOM-W1 (as Satellite B) and OCO-2 (as Satellite A). |

### 4.1.6. OCO-2 In A Prolonged Safe-hold

**DESCRIPTION**

If OCO-2 remains in a prolonged safe-hold, it will drift and eventually leave the Afternoon Constellation (see Figure 4-10).

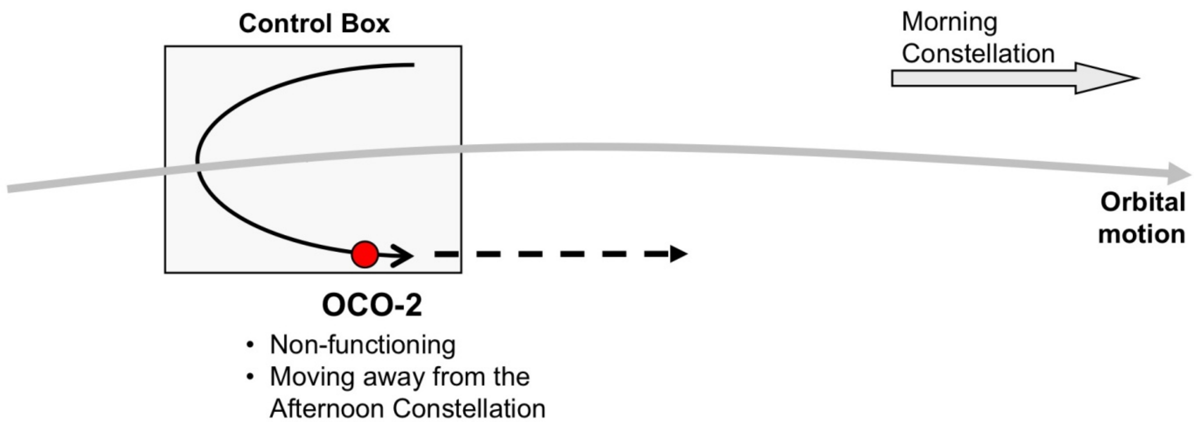


*Figure 4-10. Collision Avoidance Scenario Involving OCO-2*

**ANALYSIS**

Since OCO-2 will be a large distance in front of the rest of the Constellation, it should pose no immediate danger if it loses orbital control. Phase analysis between OCO-2 and Terra in the Morning Constellation shall be performed to minimize the slight risk of OCO-2 drifting too close to Morning Constellation satellites.

**PROCEDURE**

| |
|---|
| The OCO-2 mission team shall coordinate its situations with the Morning Constellation teams if the OCO-2 satellite starts to present a credible risk to their satellites. |

## 4.2. CALIPSO In A Prolonged Safe-hold

**DESCRIPTION**

If CALIPSO remains in a prolonged safe-hold and has lost orbital control, it will drift and eventually enter Aqua's Alert ZOE. This scenario differs from the earlier ones in that if the formation is maintained, this drifting motion will force CloudSat into Aqua's Alert ZOE as well (see Figure 4-11).

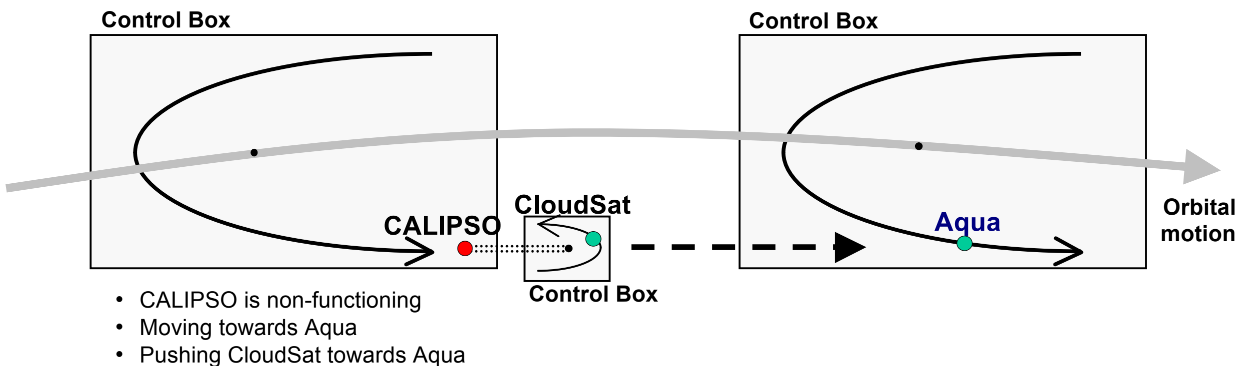


*Figure 4-11. CALIPSO in Prolonged Safe-Hold*

**ANALYSIS**

CALIPSO nominally moves along its circulation orbit in 35 to 130 days (depending on the level of atmospheric drag). As such, the "worst–case" scenarios addressed below may be favorably biased by up to 35-130 days, depending on *where* in the circulation orbit the safe-hold occurs.

A second variable is the location of Aqua during this safe-hold. This can greatly influence whether/when a close approach will occur.

A final complication is the position of CloudSat. If CloudSat maintains its formation with a CALIPSO in safe-hold, it will be forced into Aqua's control box and Alert ZOE. Under these circumstances, CloudSat is allowed to enter Aqua's control box, but is to maneuver (a) before it enters Aqua's Alert ZOE and (b) at least 4 days before closest approach with Aqua, whichever comes first.

Under the highest recorded atmospheric drag while at the worst locations and if no actions are taken:

a) CALIPSO will leave its Control Box in 0.4 days
b) CloudSat will be forced into Aqua's Control Box in 2.2 days
c) CALIPSO will enter Aqua's Control Box in 6 days
d) A CALIPSO close approach with Aqua will occur in about 9 days.

Under typical atmospheric drag while at the worst location and if no actions are taken:

a) CALIPSO will leave its Control Box in 1 day

b) CloudSat will be forced into Aqua's Control Box in 7 days

c) CALIPSO will enter Aqua's Control Box in 14 days

d) A CALIPSO close approach with Aqua will occur in about 21 days

## PROCEDURE

This scenario is more complex due to the introduction of a third satellite (i.e., CloudSat) being forced into the Control Box (and eventually the ZOEs) of a functioning satellite (Aqua) if left unchecked. This is further based on the assumption that CloudSat will, at least initially, attempt to maintain its formation flying with CALIPSO. The standard collision avoidance procedure in Section 4.1 shall still be followed, although perhaps in a non-intuitive approach. Note that consultations with CNES (to determine the CALIPSO satellite status/prognosis) and with the Afternoon Constellation project scientist and mission principal investigators will occur prior to execution to ensure overall mission objectives are met.

| | |
|---|---|
| **Step 1.** | First, CloudSat must be treated as the functioning, maneuverable satellite being "approached" by a "non-maneuverable" Aqua. As such, CloudSat assumes the role of Satellite A, while Aqua assumes the role of Satellite B. As per the earlier collision avoidance procedure, CloudSat will need to execute an evasive maneuver, avoiding both Aqua and CALIPSO. CloudSat shall perform this maneuver no later than 4 days from its closest approach with Aqua and before it enters Aqua's Alert ZOE (whichever occurs first). Once leaving the formation, the CloudSat CMO shall set its Constellation Status flag in CCS to "Yellow". |
| **Step 2.** | The roles then shift. CALIPSO will now properly be considered the non-functioning Satellite "B" and Aqua the functioning Satellite "A". The collision avoidance procedure then repeats. The only additional complication is that CloudSat may still be in the immediate vicinity. Aqua will need to design its maneuver so that it avoids both satellites. |
| **Step 3.** | CloudSat will no longer be formation flying. Recovery of the constellation configuration will be decided by the MOWG and the science teams and will depend on the status of all 3 satellites. |

## 4.3. Drag Makeup Maneuver Too Large For Missions Having Retrograde Capability (Glory, CALIPSO, CloudSat, GCOM-W1, and OCO-2)

**DESCRIPTION**

If a satellite executes an orbit-raising maneuver that exceeds its target to the extent that the satellite will leave its Control Box and places another constellation satellite at risk, a corrective maneuver will be required for missions that have retrograde maneuver capability (see Figure 4-12).

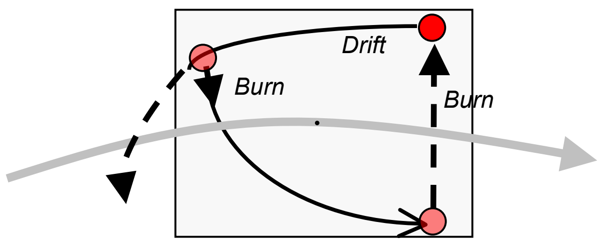


*Figure 4-12. Drag Makeup Maneuver Too Large (Retrograde maneuver capability available)*

**ANALYSIS**

It is desirable for the satellite to correct its orbital position early by performing a retrograde burn, before it can stray near any other satellites in the Constellation. The urgency of a retrograde maneuver will depend on the magnitude of the over-burn.

**PROCEDURE**

| | |
|---|---|
| **Step 1.** | Once a satellite team has determined that its drag makeup maneuver exceeded its target to the extent that the satellite will leave its Control Box, it shall generate a maneuver plan to prevent the Control Box violation.<br>Note that the satellite team has the alternative option to request approval for a Control Box violation (see section 4.5 for that procedure). |
| **Step 2.** | The Satellite team shall provide a new "burn" ephemeris to CCS, which will confirm that the new burn will prevent the satellite from leaving its Control Box. |
| **Step 3.** | The Satellite team shall execute the corrective burn, and then supply the revised predictive ephemeris to CCS for verification. CCS shall send out e-mail notifications as described earlier in this document. |
| **Step 4.** | If the satellite does leave its Control Box, the CMO shall set the Constellation Status flag to "Yellow". The standard collision avoidance procedure in Section 4.1 shall be followed to ensure that there are no unacceptable close approaches with any other Constellation satellites.<br>Once the satellite has returned to its Control Box, the CMO shall set the Constellation Status flag to "Green". CCS shall send out e-mail notifications as described earlier in this document. |

## 4.4. Drag Makeup Maneuver Too Large for Missions Without Retrograde Capability (Aqua or Aura)

**DESCRIPTION**

If a satellite executes an orbit-raising maneuver that exceeds its target to the extent that the satellite will leave its Control Box, a corrective maneuver would be desired, but will not be possible for missions lacking retrograde maneuver capability, i.e., Aqua and Aura (see Figure 4-13).

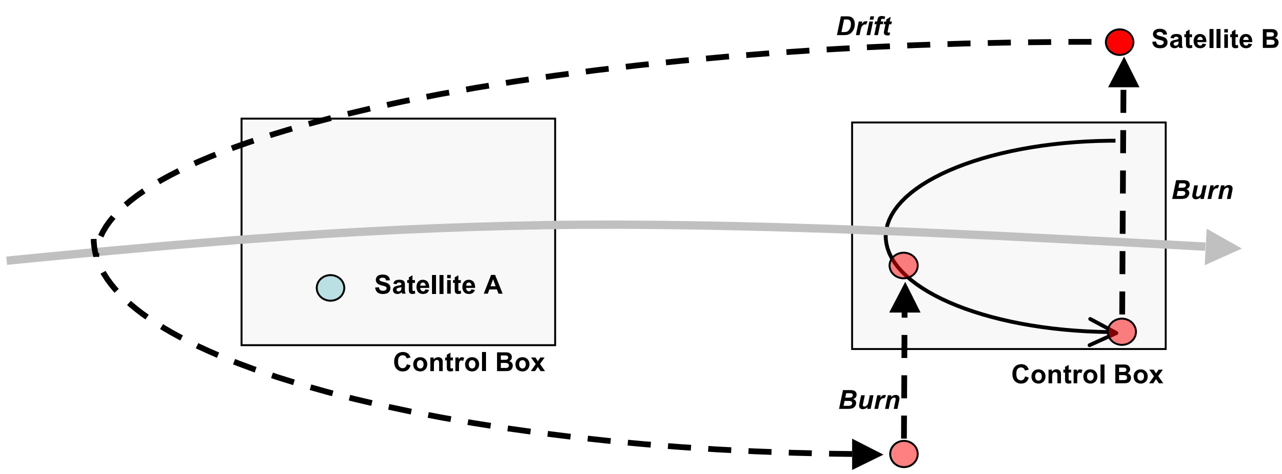


*Figure 4-13. Drag Makeup Maneuver Too Large (No Retrograde Maneuver Capability Available)*

**ANALYSIS**

Since no retrograde maneuver capability exists for Aqua or Aura, they will be forced to wait until they have drifted sufficiently down (in sma) from the effects of drag before they can execute a corrective orbit-raising maneuver. Depending on the extent of the over burn, this could place other satellites in jeopardy. This could escalate into a standard Satellite A/Satellite B collision avoidance scenario, except that both satellites retain propulsive capability. The prime responsibility to rectify this situation rests with the satellite that performed the over burn (i.e., Satellite B), but other satellites may offer to perform evasive maneuvers, at their discretion.

## PROCEDURE

| | |
|---|---|
| **Step 1.** | Once the satellite B team (either Aqua or Aura) has determined that its drag makeup maneuver exceeded its target to the extent that the satellite will leave its Control Box, it shall generate an ephemeris to determine if there are any predicted close approaches with other satellites. The standard collision avoidance procedure in Section 4.1 shall be followed to ensure that there are no close approaches to any other Constellation satellite. |
| **Step 2.** | If there are no close approaches predicted with any other satellites, then there is no further action required until satellite B has left its Control Box. |
| **Step 3.** | If/when the satellite does leave its Control Box, the CMO shall set the Constellation Status flag to "Yellow". CCS shall send out e-mail notifications as described earlier in this document. |
| **Step 4.** | If there is a predicted violation of another satellite's Alert ZOE, the MOWG will be convened to discuss the options. |

## 4.5. Approved Control Box Violations

**DESCRIPTION**

For efficient operations, a satellite may find it advantageous to leave its Control Box for a short period (i.e., a few days).

**ANALYSIS**

Each satellite team will make every effort keep its satellite inside its Control Box. If there is a Control Box excursion, each satellite team will make its best effort to return its satellite to its Control Box as soon as possible.

Planned Control Box excursions (Figure 4-14) can be submitted for approval if and only if the following conditions are satisfied:

- The satellite retains full capability to perform propulsive maneuvers
- The excursion shall not endanger any other satellite; in particular, the planned excursion shall not go past *the halfway point into the buffer zone between it and the nearest satellite*
- The excursion provides advantages to the satellite's operations
- The excursion shall not dramatically impact correlated science observations with any other Afternoon Constellation satellite (unless approval was received from that science team)
- Notice is provided to all Afternoon Constellation teams at least 5 days prior to the Control Box violation.

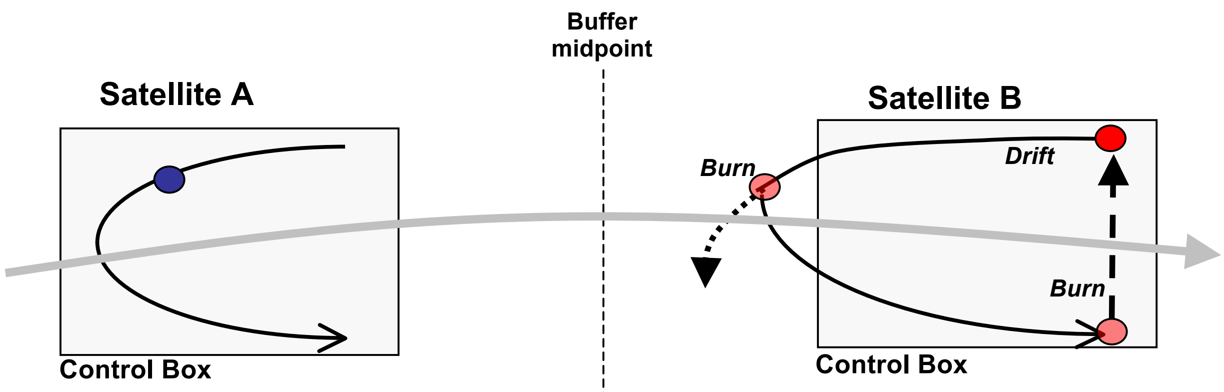


***Figure 4-14. Satellite B Executing an Approved Control Box Violation***

## PROCEDURE

Once a satellite team has decided that it is advantageous for its satellite (call it Satellite B) to leave its own Control Box on an anticipated excursion, there are a number of steps to be followed.

| | |
|---|---|
| **Step 1.** | The Satellite B team shall generate an ephemeris and use it to confirm that the criteria for the Control Box excursion (listed under the Analysis section above) are satisfied. The team shall continue to upload the ephemeris to CCS as per standard procedure. |
| **Step 2.** | At least 5 days before the predicted excursion, the Satellite B team shall notify the other MOWG teams of its intentions via e-mail message stating the reason for the planned excursion and its extent (in both time and distance). The Satellite B team shall provide an opportunity for other Afternoon Constellation teams to respond with any concerns. |
| **Step 3.** | If objections are raised by any team(s), the Satellite B team may try to address the concerns in order to receive concurrence for the proposed excursion.<br>If there is a disagreement as to any proposed course of action that cannot be resolved through discussion and negotiation, then the conflict resolution procedure outlined in the ACOCP Section 7, shall be invoked. There must be sufficient time allotted for the conflict resolution process to run its course. |
| **Step 4.** | If no objections are raised by any Afternoon Constellation team(s), the Satellite B team may continue planning for its proposed excursion and planned return |
| **Step 5.** | Once Satellite B has left its Control Box, the Satellite B CMO shall set the Constellation Status flag from “Green” to “Yellow” and CCS shall send out e-mail notifications as described earlier in this document. |
| **Step 6.** | Once Satellite B returned to its Control Box, the Satellite B CMO shall reset the Constellation Status flag from “Yellow” to “Green” and CCS shall send out e-mail notifications as described earlier in this document. |

## 4.6. A Missed Maneuver During A CALIPSO/CloudSat Coordinated Drag Make-up Maneuver

**DESCRIPTION**

To satisfy their formation flying requirements, CALIPSO and CloudSat coordinate their drag make-up maneuvers and execute them almost concurrently. Coordination details are contained in the CALIPSO/CloudSat ICD. A CALIPSO drag make-up maneuver consists of two burns separated by approximately one and a half orbits. The first burn is always planned to be in the blind (although this is not a requirement). An S-Band ground contact will occur one orbit after the second burn. Maneuver notification will be available at this time via email and fax. One orbit later, a second ground contact is scheduled. After this pass, the updated ephemeris will be available for distribution to CCS/CloudSat.

**ANALYSIS**

If CALIPSO fails to execute either of its planned burns in its drag make-up maneuver and CloudSat executes its maneuver as planned, CloudSat will be on a post-maneuver trajectory relative to CALIPSO that will result in an undesired close approach, typically in two days, unless CloudSat promptly executes an "undo" maneuver. An undo maneuver cancels the effect of CloudSat's drag make-up maneuver arresting its motion toward CALIPSO and preventing a close approach between CloudSat and CALIPSO.

If CloudSat fails to execute its corresponding drag make-up maneuver, it will break formation with CALIPSO, but will not immediately endanger CALIPSO or any other Constellation satellite.

**PROCEDURE FOR NOMINALLY CONDUCTING THE CALIPSO/CLOUDSAT DRAG MAKE-UP MANEUVER**

The sequence of events for CALIPSO/CloudSat coordinated drag make-up maneuver is summarized in Table 4-1. This table is taken from the CALIPSO/CloudSat ICD, updated 22 July 2005.

The real timing of maneuvers occurring during this coordinated event, however, is more dynamic due to variability of CloudSat's state while flying in formation with CALIPSO. Whereas CloudSat will need to execute a maneuver nearly identical in magnitude to the CALIPSO drag makeup maneuver at approximately the same time, the precise timing and size of CloudSat's maneuver will depend on the size of CALIPSO's maneuver and CloudSat's relative position and velocity within its control box at the time of CALIPSO's maneuver. Typically, CloudSat's drag make-up maneuver will take place about one day after the CALIPSO maneuver, but it could occur as early as between CALIPSO's two burns or as late as three days after CALIPSO's maneuver. Under no circumstance would CloudSat execute its drag make-up maneuver before CALIPSO's first burn.

Embedded in this nominal procedure is a risk mitigation action taken by CloudSat to avoid a contingency situation from occurring should the CALIPSO satellite fail to execute its drag make-up maneuver per the plan. In particular, if the timing is such that the CloudSat maneuver is to be uploaded to the CloudSat spacecraft before CloudSat has received confirmation from CALIPSO that its burn has executed, then CloudSat develops and loads two sets of maneuver commands into the spacecraft memory for its drag make-up maneuver. The first is consistent with CALIPSO's planned drag make-up maneuver. The second is nearly identical in magnitude but opposite in direction to the original maneuver and in effect does an "undo" maneuver. The execution of this "undo" maneuver arrests unwanted motion of CloudSat toward CALIPSO and averts a contingency situation from developing. The “undo” maneuver is scheduled 12 to 24 hours following CloudSat’s drag makeup maneuver, but will be cancelled from the ground when CloudSat gets confirmation that the CALIPSO drag makeup maneuver has executed. Note that CloudSat has not historically employed this undo process due to low atmospheric drag (which means that CloudSat has more time to react to CALIPSO’s maneuver). CloudSat undo maneuvers may be loaded once atmospheric drag increases.

**<u>CONTINGENCY PROCEDURE</u>**

After the attempted execution of their drag make-up maneuver, CALIPSO provides to CloudSat a notification of the maneuver's success or failure by e-mail and fax. In the event that CALIPSO drag make-up maneuver failed, there are two possible scenarios requiring prompt action:

If there is sufficient time for CloudSat to rescind the execution of its preloaded maneuver commands, the nominal drag make-up maneuver and the "undo" maneuver will be aborted by erasing the commands from spacecraft memory during a tracking station contact prior to the first maneuver executing

If, on the other hand, the first maneuver is executed prior to receipt of the message from CALIPSO about the ill-fated burn, then CloudSat would allow the "undo" maneuver to execute as planned. In the event of the "undo" maneuver, it will occur between 12 and 24 hours after the execution of the drag make-up maneuver.

*Table 4-1 CALIPSO/CloudSat Drag Makeup Maneuver Coordination*

**(Source: CALIPSO/CloudSat ICD, dated 22 July 2005)**

| Activity | Minutes | Hours |
|---|---|---|
| Operational Coordination Group telecon* | <Tuesday prior to Burn 1> | |
| CALIPSO Burn 1 | 0 | 0.0 |
| CloudSat Burn | <After CALIPSO's Burn 1> | |
| CALIPSO Burn 2 | 150 | 2.5 |
| CALIPSO ground contact | 250 | 4.2 |
| Notification of success or failure to CloudSat by email and FAX | 260 | 4.3 |
| Operational Coordination Group telecon* | 265 | 4.4 |
| CALIPSO ground contact 2 | 350 | 5.8 |
| CALIPSO Orbit products to CloudSat | 410 | 6.8 |
| CS Undo Automatic Burn (if required)** | <Between approximately 12 and 24 hours after CloudSat's burn> | |

* CNES, LaRC, JPL, KAFB, and the ESMO Constellation management group attending

** Cancelled if the CALIPSO maneuver executes as planned

## 4.7. CloudSat or CALIPSO Falling Into A Safe-hold During L&EO Operations Prior To Capturing Into Their Operational Orbits and Establishing Formation With One Another

***(This procedure is outdated, but has been retained for historical reasons)***

**DESCRIPTION**

The CloudSat and CALIPSO ascent plans are "independent, but coordinated". They were designed for minimal interaction between the two mission teams under nominal conditions.

If either satellite falls into safe-hold during L&EO operations prior to entering the Afternoon Constellation, the other satellite team plans to proceed with its own ascent plan and join the constellation according to its original schedule.

**ANALYSIS AND PROCEDURE**

The CloudSat and CALIPSO ascent plans are beyond the scope of this document, but the general agreement is as follows:

- If CloudSat falls into Safe-hold, the CALIPSO team plans to perform its ascent maneuvers according to schedule and place its satellite in its Control Box.
- If CALIPSO falls into Safe-hold, the CloudSat team plans to perform its ascent maneuvers according to schedule and enter the Afternoon Constellation. It will not be able to fly in formation until CALIPSO joins the constellation. Under these circumstances, CloudSat would take up a position 20 seconds ± 5 seconds along-track behind Aqua's Control Box and would basically station keep at that this position until CALIPSO succeeded in entering its Control Box. If CALIPSO cannot reach its Control Box, the CloudSat team will need to recommend its planned approach for flying in the constellation without CALIPSO to the MOWG and science teams.

## 4.8. Predicted Close Approach With Space Debris Catalog Objects

**DESCRIPTION**

The possibility of collision with space debris is increasing all the time. A collision could disable an Afternoon Constellation satellite and the resulting debris field could threaten all member satellites. Afternoon Constellation satellites need to be prepared to perform evasive maneuvers if a credible risk of collision is identified.

The ESMO Project has taken the lead role in researching the options available to predict close approaches with space debris. This has developed as a joint effort with the U.S. Air Force (USAF).

**PROCEDURE**

Afternoon Constellation missions supply their ephemerides to CCS as part of normal operations. The ESMO Project provides these ephemerides to the USAF on a routine basis for screening. A process and procedures have been established to interpret the screening results and work with member missions to mitigate identified risks. Please refer to RD5 in Section 1.3 for the CA procedures that govern close approaches with space debris.

Note that the CloudSat mission team uses the debris avoidance predictions available from the USAF through Kirtland Air Force Base (KAFB).

## 4.9. CCS Unavailable For An Extended Period

**DESCRIPTION**

If CCS is unavailable for more than a few days, there are two impacts:

1. Measures must be taken to ensure that constellation satellites are safe from close approaches
2. Backup means must be applied to transfer and convert Constellation data products.

**ANALYSIS**

Each satellite team knows whether their satellite is within its Control Box. As long as all satellites remain so, there is no short-term threat of a close approach to each other.

There are numerous Constellation data products shared between users (see Appendix D). An alternative route for product delivery must be used whenever there are extended CCS outages.

**PROCEDURE**

The actions required depend on the nature of the outage and its expected time to return to service. These can range from hardware/software anomalies to external factors (network or facility outages).

| | |
|---|---|
| **Case 1** | If the CCS file transfer protocol (FTP) or secure FTP (sFTP) server has gone down for an extended period, CCS administrators will notify the Satellite CMOs and recommend mitigation procedures. |
| **Case 2.** | • If no CCS capabilities are available or accessible, each Constellation team will assume new responsibilities to avoid Control Box violations and close approaches:<br>• Each team shall notify all other teams immediately when its satellite has lost orbital control and/or left its Control Box<br>• Each team shall transfer their ephemeris data to other teams via e-mail, FTP, or sFTP. The file formats differ, but this is the only approach available without the conversions performed at CCS. Flight Dynamics analysts at each site will convert the data provided by other satellites (manually if necessary) to the desired format on a best effort basis.<br>• If a close approach is predicted (either from the ephemeris data from other teams or by notification from the USAF), then the standard collision avoidance procedure in Section 4.1 shall be followed to the extent possible. |

## 4.10. Landsat 5 Orbit Crossings

**DESCRIPTION**

Landsat 5 and the Afternoon Constellation satellites all follow similar 705 km orbits. Their orbits intersect near the poles. In February 2010, it was discovered that Landsat 5 was crossing through the orbit intersections at the poles between CloudSat and CALIPSO. In the next several weeks, Landsat 5 passed behind CALIPSO. Further investigation revealed that a Landsat 5 passage from in front of to behind the A-Train had occurred in late 2004, a passage from behind to in front of the A-Train had occurred in 2008, and that the third passage (from in front of to behind the A-Train) started in late 2009.

**ANALYSIS**

A Red Team consisting of both Landsat 5 and the Afternoon Constellation stakeholders was formed in March 2010 to analyze the situation and determine the best courses of action to minimize risks while continuing to provide the most science return from all satellites. The final recommendation coming from the Red Team meeting held at Goddard Space Flight Center on April 21-22, 2010 was that a managed crossing approach should be adopted, taking advantage of the highly predictable nature of the orbits. This approach depends on the following assumptions being true:

- A minimum separation during close approaches of 400 meters,
- At least one of the two missions having a close approach maintains positive control,
- Any Afternoon Constellation mission or Landsat-5 that experiences an anomaly, failure, or need to exercise debris avoidance prior to a planned maneuver shall immediately provide such information to all other missions, and
- Contingency plans, including triggers, shall be documented within the crossing implementation plan.

**PROCEDURE**

The procedure to manage the Landsat 5 crossings with the Afternoon Constellation is found in RD4 in Section 1.3.

# Appendix A. Afternoon Constellation Mission Team Contacts

| Mission | Ground System/Ops Lead |
|---|---|
| Aqua | Mission Director: Bill Guit / GSFC, 301-614-5188, william.j.guit@nasa.gov<br>Console (24x7): 301-614-6755, pm1ops@eoc.ecs.nasa.gov |
| Aura | Mission Director: Bill Guit / GSFC, 301-614-5188, william.j.guit@nasa.gov<br>Console (24x7): 301-614-5016, ch1ops@eoc.ecs.nasa.gov |
| CloudSat | Don Keenan/RSC, 505-846-7062, donald.e.keenan@aero.org<br>RSC Control Room (24x7), 505-853-3738 |
| CALIPSO | Ron Verhappen, 757-864-2405 office, 757-358-2359 cell, ron.verhappen@nasa.gov<br>Dave MacDonnell, 757-864-5130 office, 757-272-4906 cell, david.g.macdonnell@nasa.gov<br>On-Call Operator (24*7): 757-232-4990, oncallops@tmo.blackberry.net<br>migs.ops@cnes.fr for CALIPSO/Parasol contingency |
| GCOM-W1 | Norimasa Ito, +81-50-3362-7409, Ito.norimasa@jaxa.jp |
| Glory | Darrell Kelly, 703-948-8304, kelly.darrell@orbital.com |
| OCO-2 | Reese Wynn, 703-404-7549, wynn.reese@orbital.com<br>Joe Cavallo, 703-406-5000, cavallo.john@orbital.com<br>Console, 703-406-5000, OCO.OPS@orbital.com |
| PARASOL | Ron Verhappen, 757-864-2405 office, 757-358-2359 cell, ron.verhappen@nasa.gov<br>Dave MacDonnell, 757-864-5130 office, 757-272-4906 cell, david.g.macdonnell@nasa.gov<br>On-Call Operator (24*7): 757-232-4990, oncallops@tmo.blackberry.net<br>migs.ops@cnes.fr for CALIPSO/Parasol contingency |
| Constellation Mission Coordination | Angie Kelly/GSFC, 301-614-5317, angelita.c.kelly@nasa.gov<br>Bill Guit/GSFC, 301-614-5188, william.j.guit@nasa.gov<br>Telecons: EOS Meet Me number, 877-707-4072 x222417 |
| | |

# Appendix B. Definition of NASA Mishaps

The following is a summary of NPR 8621.1B, Sections 1.2 and 1.3.3.4, effective May 23, 2006. Expiration is May 23, 2011. Please refer to the original document for the complete procedural requirements.

NASA Mishap - An unplanned event that results in at least one of the following: (a) injury to non-NASA personnel, caused by NASA operations; (b) damage to public or private property (including foreign property), caused by NASA operations or NASA-funded development or research projects; (c) occupational injury or occupational illness to NASA personnel; (d) NASA mission failure before the scheduled completion of the planned primary mission; or (e) destruction of, or damage to, NASA property. NASA mishaps are categorized as follows:

| Classification Level & Investigation Type | Property Damage | Injury |
|---|---|---|
| **Type A Mishap** | Total direct cost of mission failure and property damage is $1,000,000 or more, *or* Crewed aircraft hull loss has occurred, *or* Occurrence of an unexpected aircraft departure from controlled flight (except high performance jet/test aircraft such as F-15, F-16, F/A-18, T-38, OV-10, and T-34, when engaged in flight test activities). | Occupational injury and/or illness that resulted in: A fatality, *or* A permanent total disability, *or* The hospitalization for inpatient care of 3 or more people within 30 workdays of the mishap. |
| **Type B Mishap** | Total direct cost of mission failure and property damage of at least $250,000 but less than $1,000,000. | Occupational injury and/or illness has resulted in permanent partial disability. *or* The hospitalization for inpatient care of 1-2 people within 30 workdays of the mishap. |
| **Type C Mishap** | Total direct cost of mission failure and property damage of at least $25,000 but less than $250,000. | Nonfatal occupational injury or illness that caused any workdays away from work, restricted duty, or transfer to another job beyond the workday or shift on which it occurred. |
| **Type D Mishap** | Total direct cost of mission failure and property damage of at least $1,000 but less than $25,000. | Any nonfatal OSHA recordable occupational injury and/or illness that does not meet the definition of a Type C mishap. |
| **Close Call** | An event in which there is no equipment/property damage or minor equipment/property damage (less than $1000), but which possesses a potential to cause a mishap. | An event in which there is no injury or only minor injury requiring first aid, but which possesses a potential to cause a mishap. |

# Appendix C. Abbreviations and Acronyms

| | |
|---|---|
| ACOCP | Afternoon Constellation Operations Coordination Plan |
| CALIPSO | Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations |
| CCS | Constellation Coordination System |
| CMO | CCS Mission Operator |
| CNES | Centre National D'Etudes Spatiales |
| DCN | Document Change Notice |
| ESMO | Earth Science Mission Operations |
| FOT | Flight Operations Team |
| FTP | file transfer protocol |
| GCOM-W1 | Global Change Observation Mission-Water |
| GPS | Global Positioning System |
| GSFC | Goddard Space Flight Center |
| JAXA | Japan Aerospace Exploration Agency |
| JsPOC | Joint Space Operations Command |
| JPL | Jet Propulsion Laboratory |
| KAFB | Kirtland Air Force Base |
| L&EO | launch and early orbit |
| LaRC | Langley Research Center |
| MOWG | Mission Operations Working Group |
| NASA | National Aeronautics and Space Administration |
| NPR | NASA Procedural Requirement |
| OCG | Operational Coordination Group |
| OCO-2 | Orbiting Carbon Observatory-2 |
| OIA | Operational Interface Agreement |
| PARASOL | Polarization and Anisotropy of Reflectances for Atmospheric Science Coupled With Observations From A Lidar |
| PM | Project Manager |
| RIC | radial, in-track, cross-track |

| | |
|---|---|
| sFTP | secure FTP |
| SMA | semi-major axis |
| TBD | to be determined |
| TBS | to be supplied |
| USAF | U.S. Air Force |
| VA | Virtual Aqua |
| WRS | Worldwide Reference System |
| ZOE | zone of exclusion |